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Ueda et al.

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(54) **EXHAUST HEAT RECOVERY DEVICE**

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CPC . ***F02G 5/02*** (2013.01); ***F01K 3/16*** (2013.01); ***F01K 9/00*** (2013.01); ***F01K 11/00*** (2013.01); ***F01K 23/065*** (2013.01); ***F01K 23/10*** (2013.01)

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CPC F01K 3/16; F01K 9/00; F01K 11/00; F01K 23/10; F01K 23/065; F02G 5/02
See application file for complete search history.

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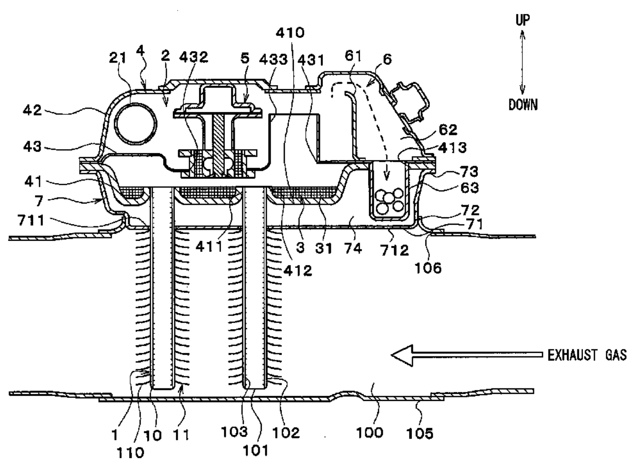
(57) **ABSTRACT**

An exhaust heat recovery device includes: a heating part for exchanging heat between a heating fluid and a working fluid; and a condensing part for exchanging heat between the working fluid evaporated by the heating part and a heated fluid to thereby condense the working fluid. The heating part has a tube in which the working fluid flows and whose upper end portion in a vertical direction is opened and whose lower end portion in the vertical direction is closed. The heating part has a storing part provided on an upper side in the vertical direction thereof, the storing part having a tube joint part to which the upper end portion in the vertical direction of the tube is joined and storing the working fluid condensed by the condensing part. The storing part has a condensed liquid holding part for holding the condensed working fluid.

20 Claims, 11 Drawing Sheets



(51) **Int. Cl.**

F01K 3/16	(2006.01)
F01K 9/00	(2006.01)
F01K 11/00	(2006.01)
F01K 23/06	(2006.01)

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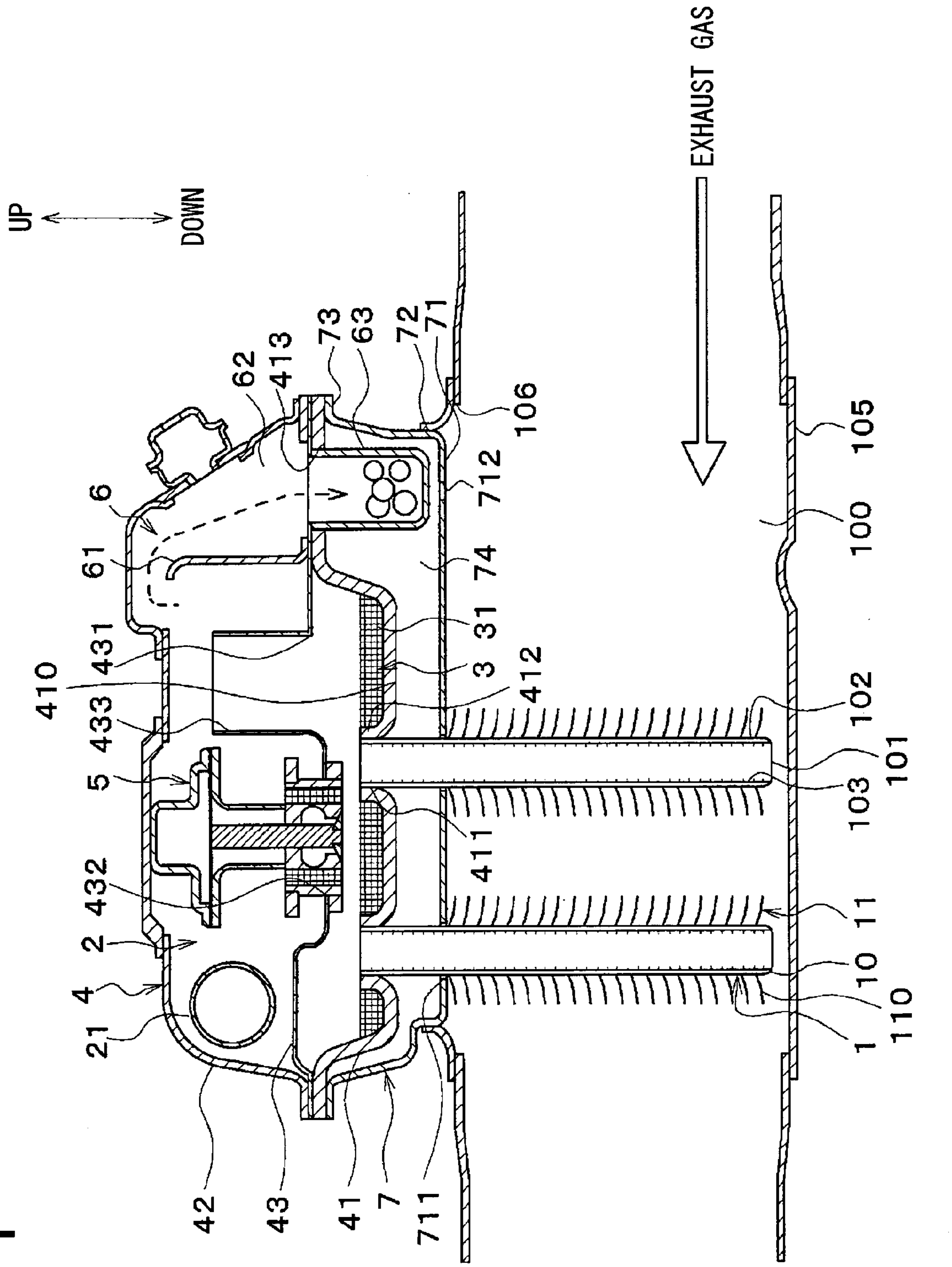

UP
DOWN
EXHAUST GAS
6
61
62
413
73
63
72
71
106
105
712
74
100
31
3
412
431
410
433
102
5
101
103
411
432
2
11
4
10
21
110
1
42
43
41
7
711

FIG. 1

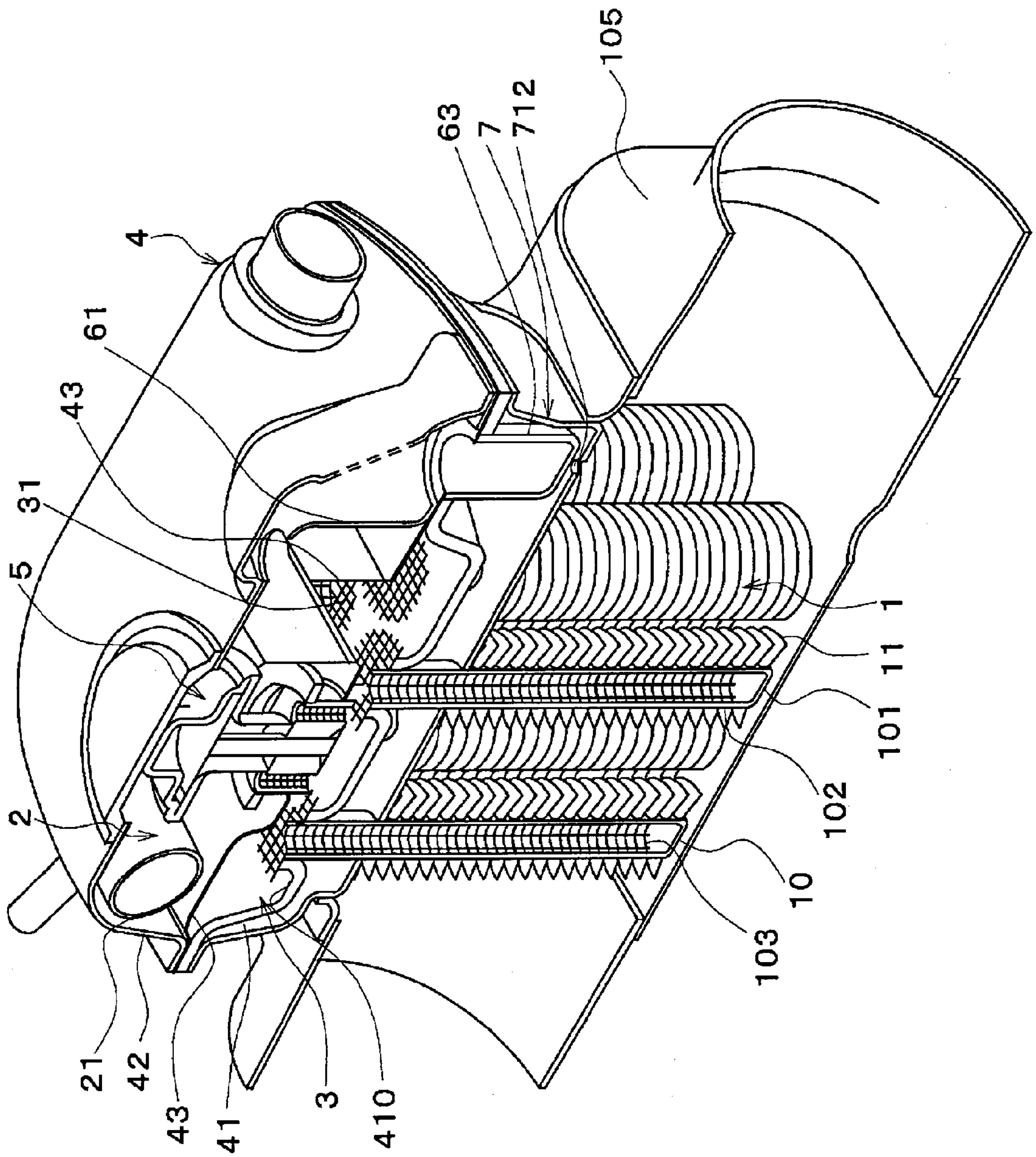


FIG. 2

FIG. 3

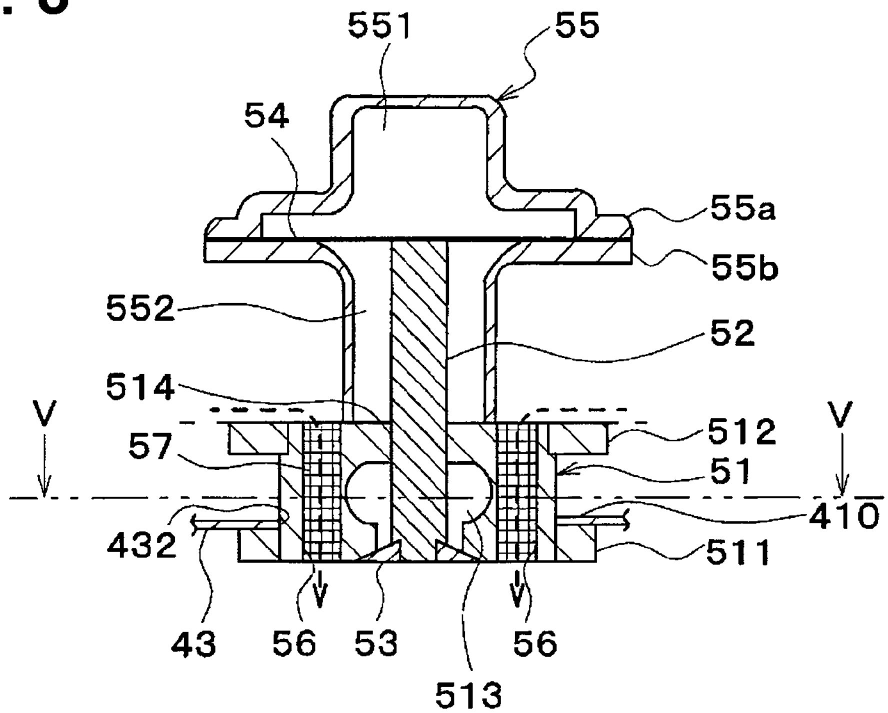
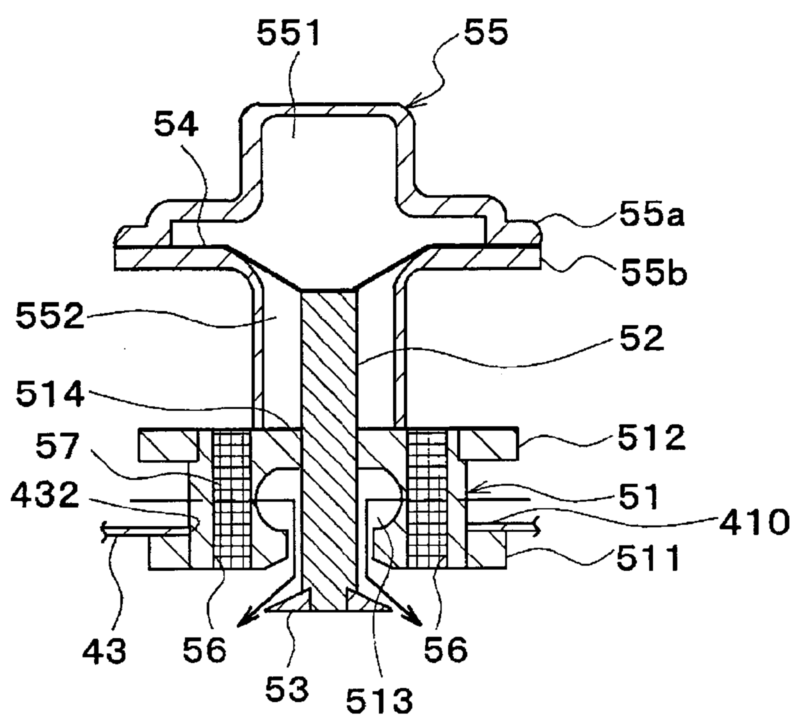

551
55
54
55a
55b
552
52
514
V
V
512
57
51
432
410
511
43
56
53
56
513

FIG. 4


551
55
54
55a
55b
552
52
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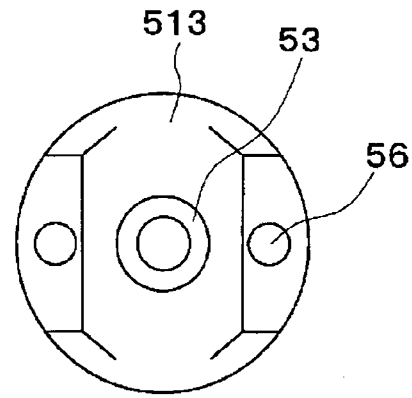
512
57
51
432
410
511
43
56
56
53
513

FIG. 5



V−V

FIG. 6

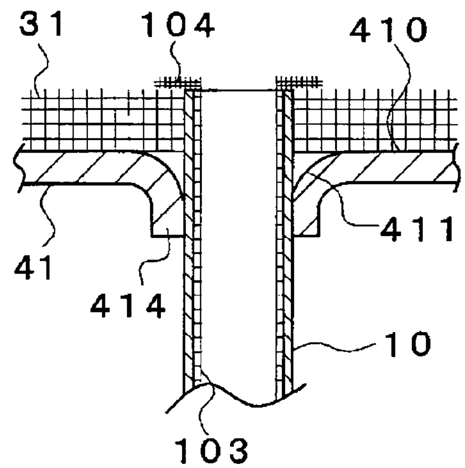
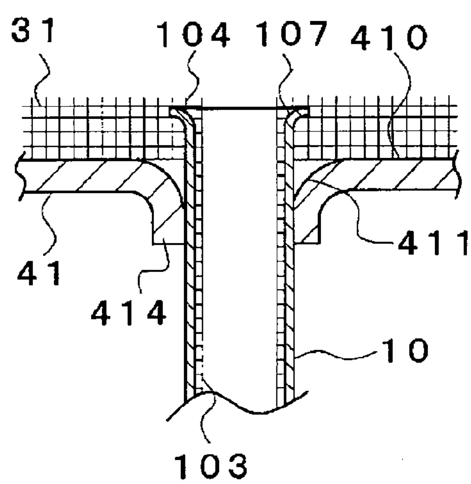


FIG. 7



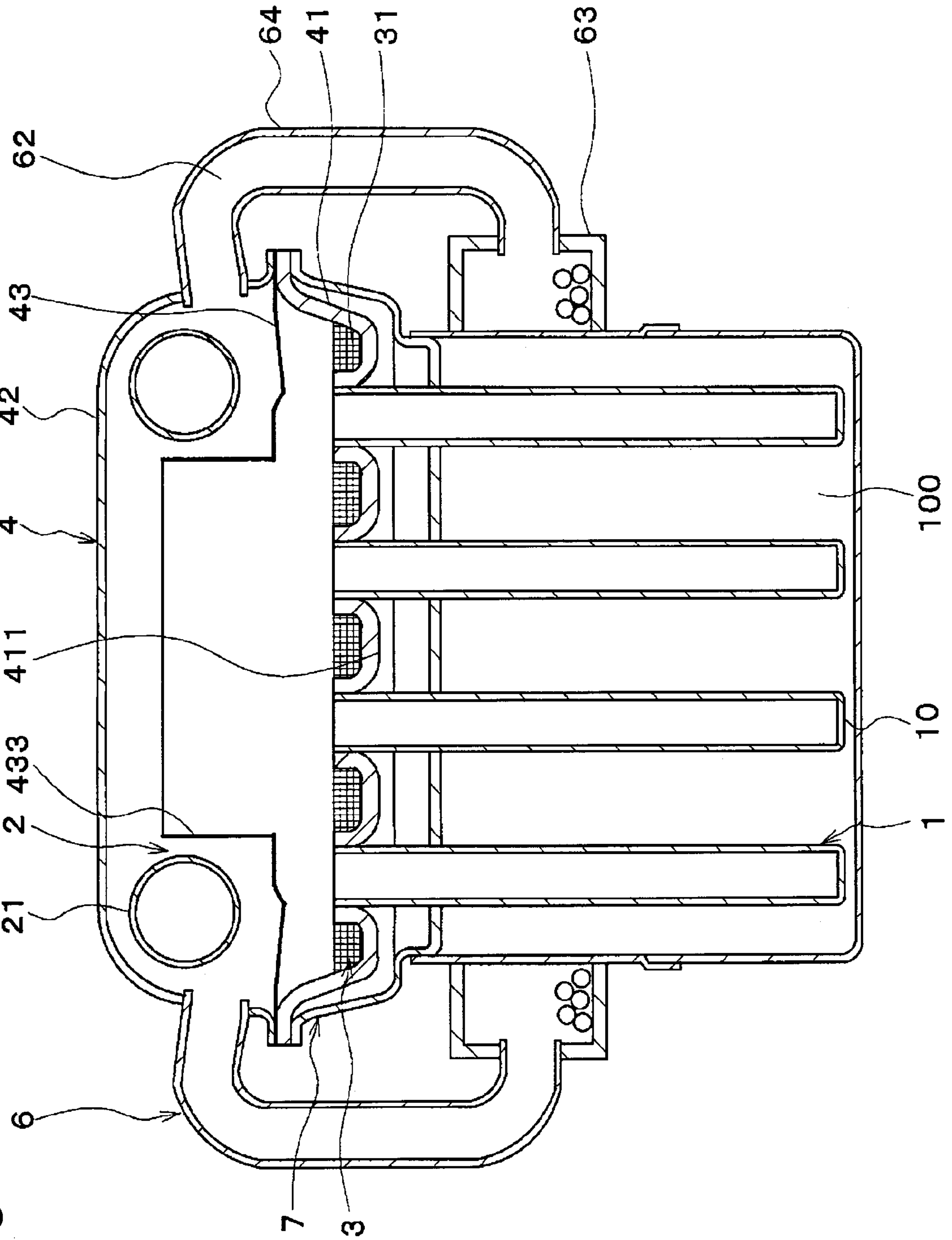


FIG. 8

FIG. 9

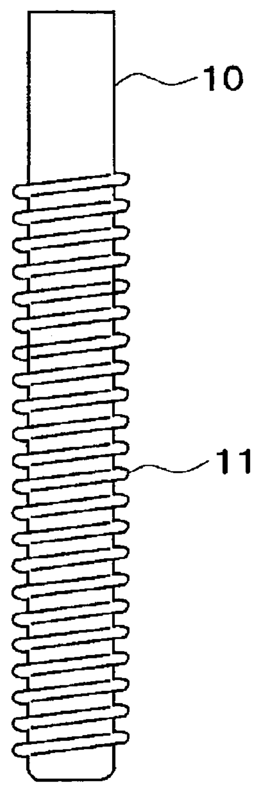


FIG. 10

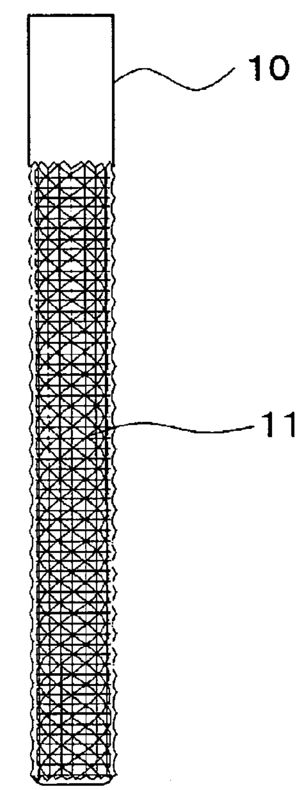


FIG. 11

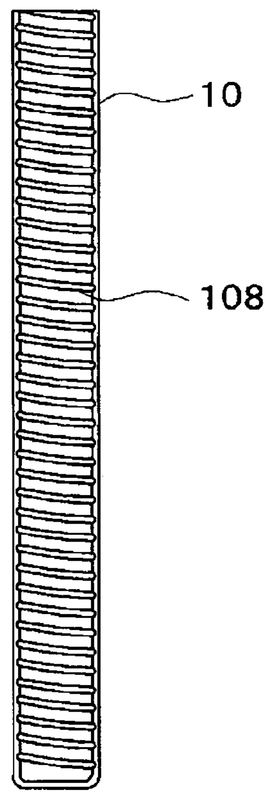

10
108

FIG. 12

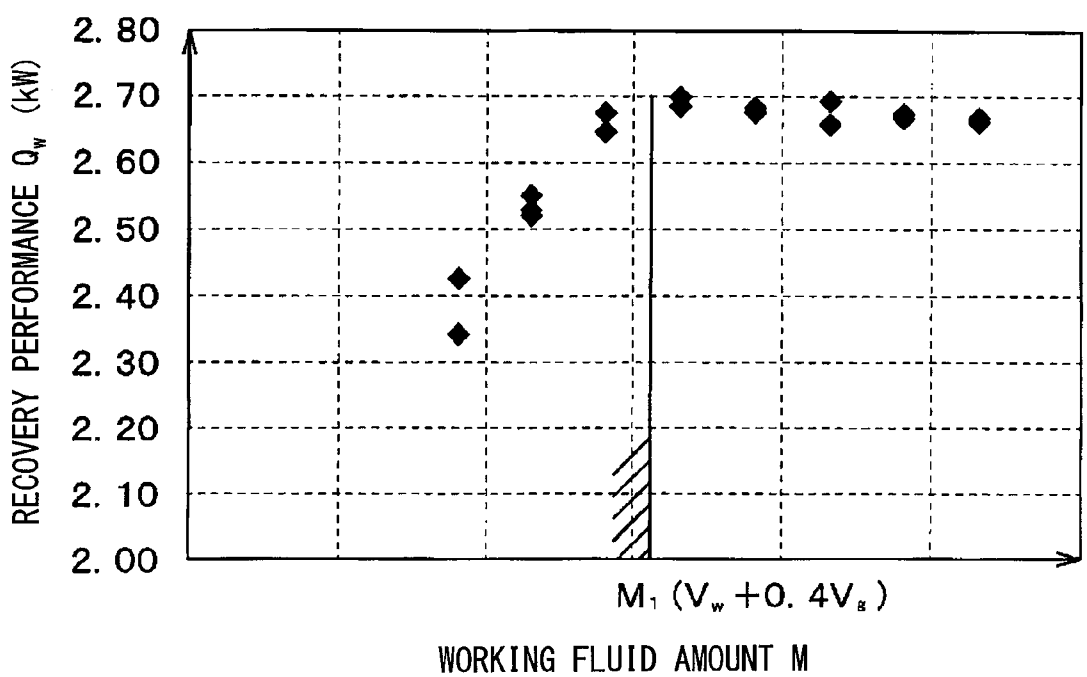
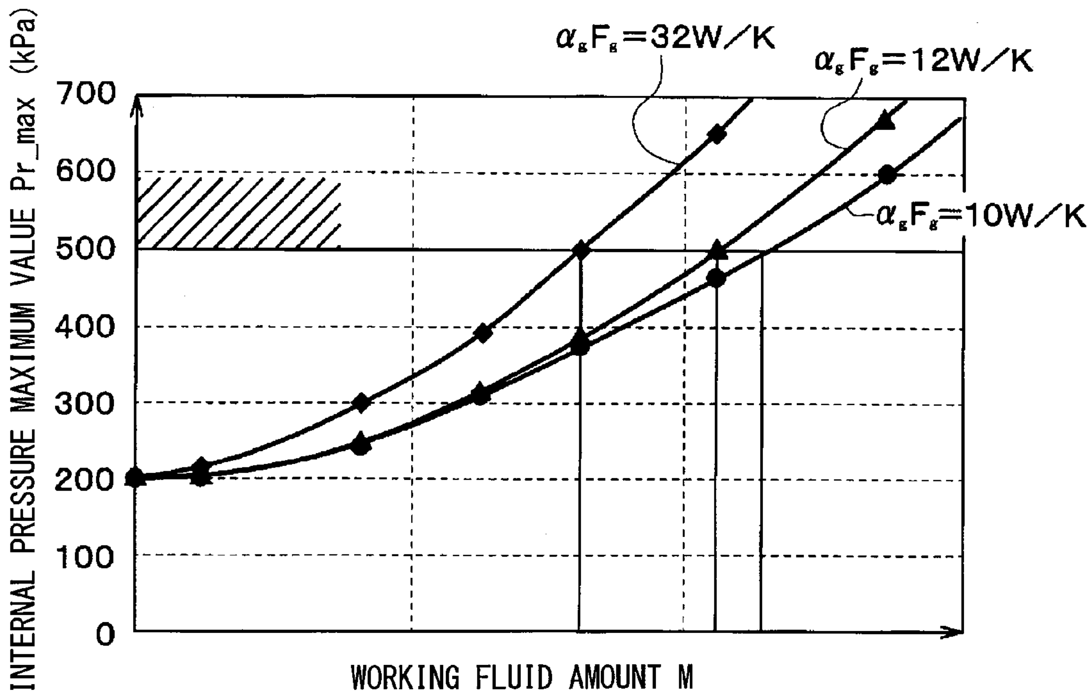
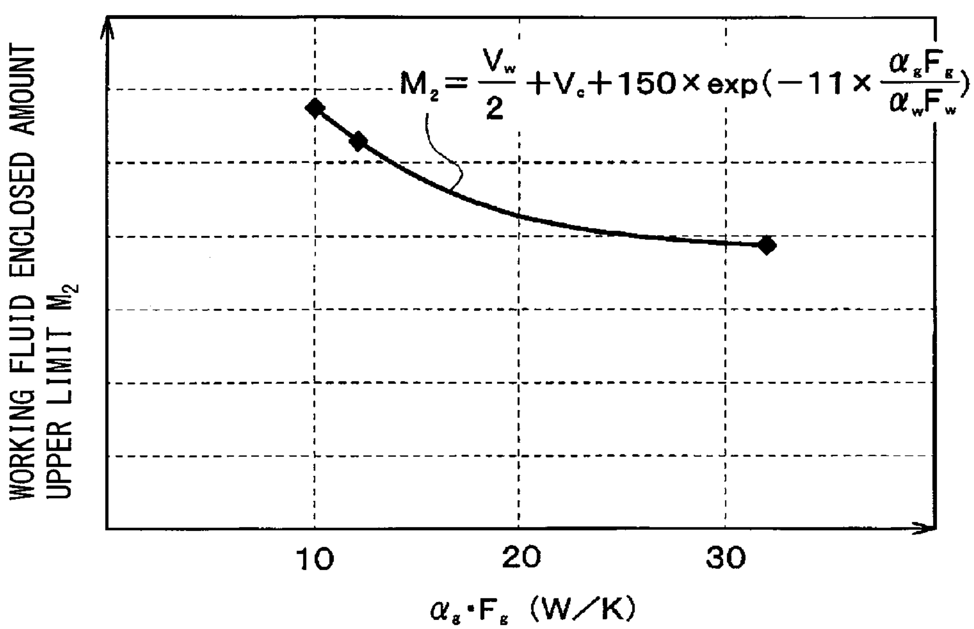

2.80
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
RECOVERY PERFORMANCE Q_w (kW)
M_1 (V_w +0.4V_g)
WORKING FLUID AMOUNT M

FIG. 13



$\alpha_g F_g$=32W/K
$\alpha_g F_g$=12W/K
$\alpha_g F_g$=10W/K
700
600
500
400
300
200
100
0
INTERNAL PRESSURE MAXIMUM VALUE Pr_max (kPa)
WORKING FLUID AMOUNT M

FIG. 14



$M_2=\frac{V_w}{2}+V_c+150\times\exp(-11\times\frac{\alpha_g F_g}{\alpha_w F_w})$
WORKING FLUID ENCLOSED AMOUNT UPPER LIMIT M_2
10
20
30
$\alpha_g \cdot F_g$ (W/K)

FIG. 15

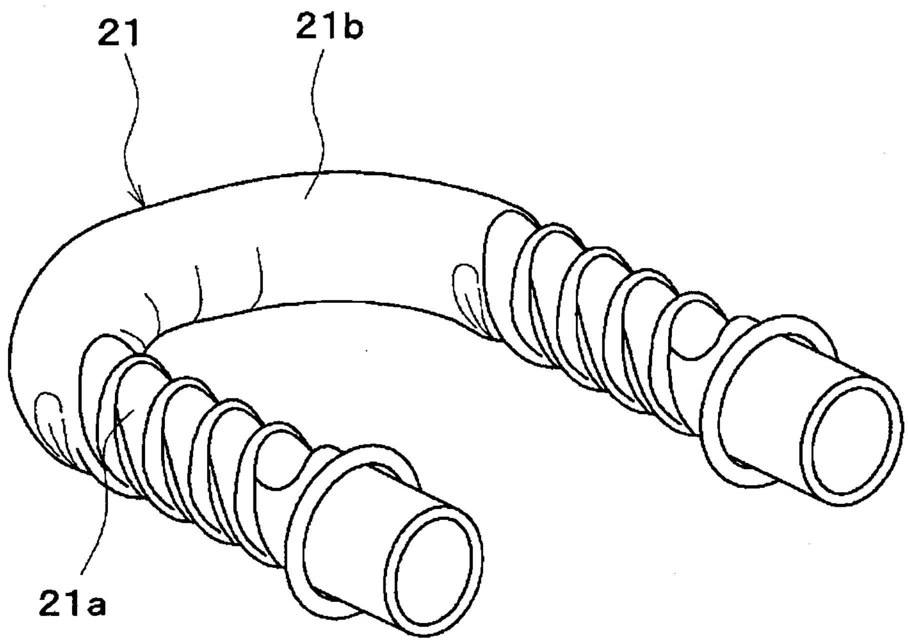


FIG. 16

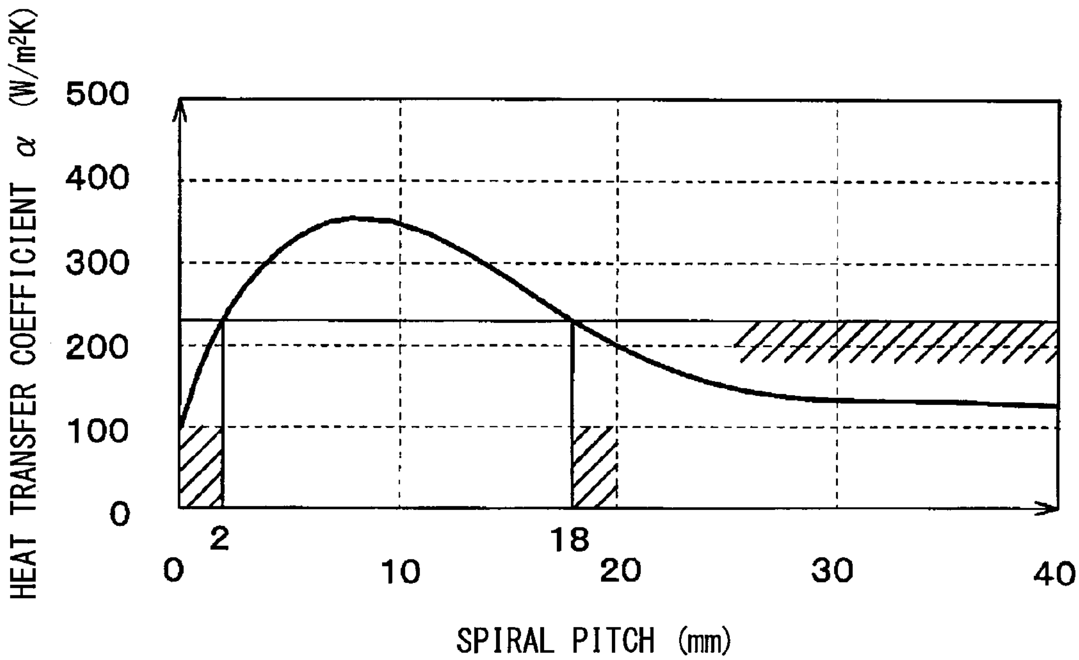

HEAT TRANSFER COEFFICIENT α (W/m²K)
500
400
300
200
100
0
2
18
0
10
20
30
40
SPIRAL PITCH (mm)

FIG. 17

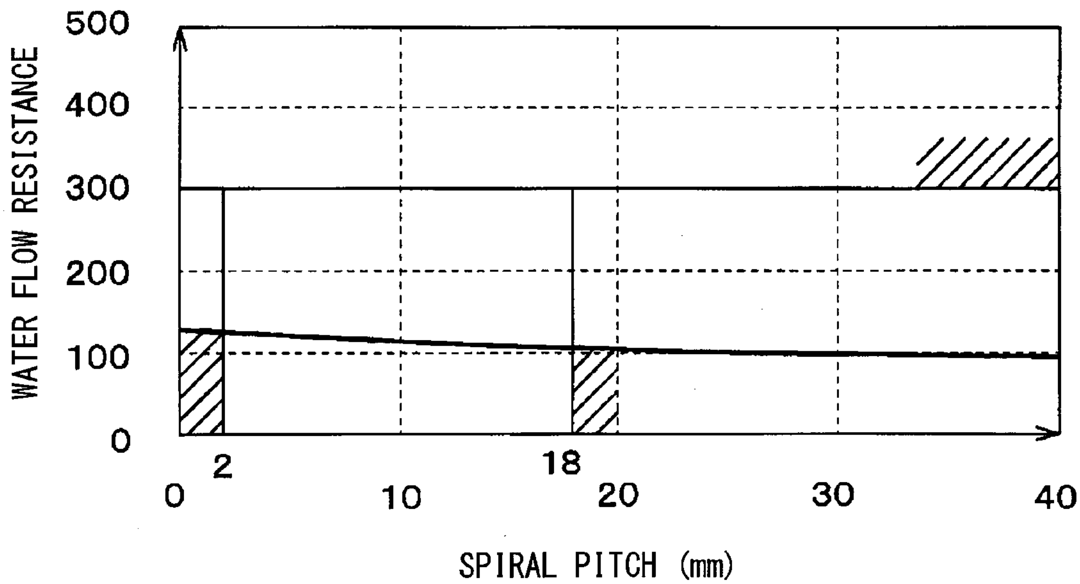

WATER FLOW RESISTANCE
500
400
300
200
100
0
2
18
0
10
20
30
40
SPIRAL PITCH (mm)

FIG. 18

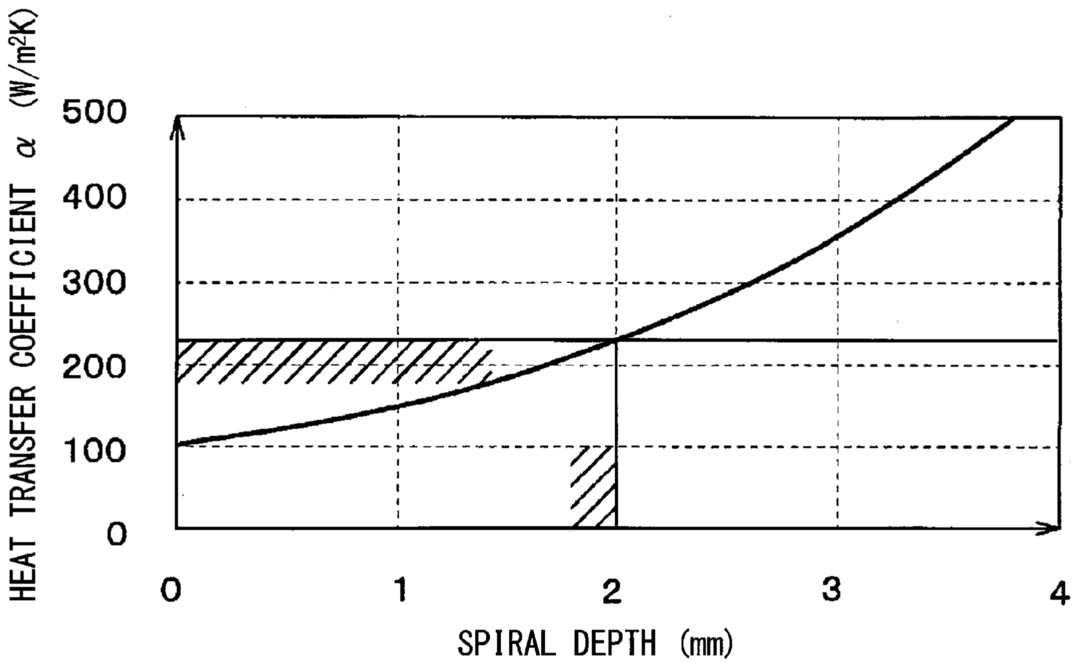
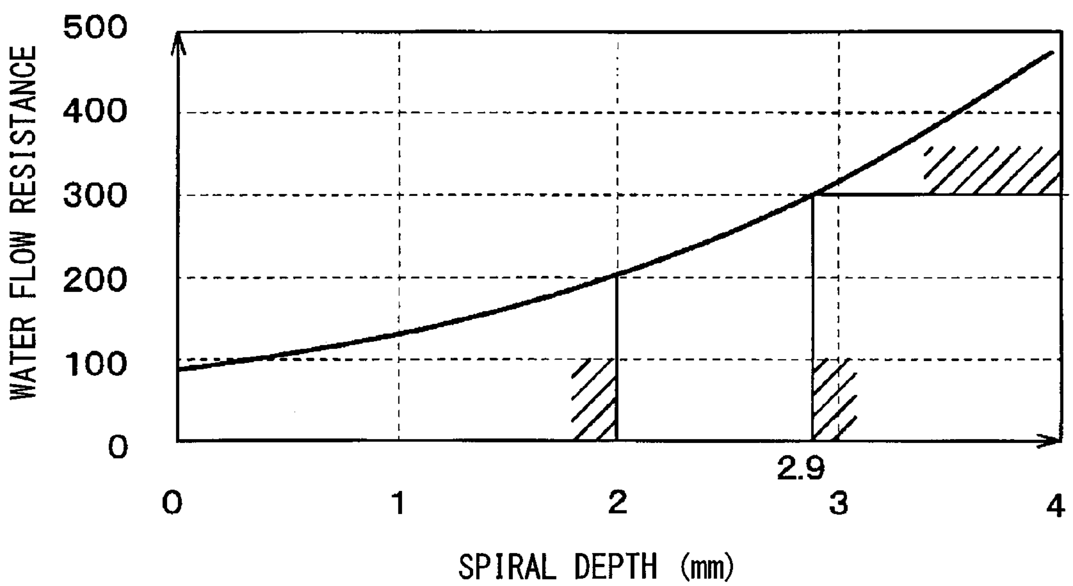

HEAT TRANSFER COEFFICIENT α (W/m2K)
500
400
300
200
100
0
0
1
2
3
4
SPIRAL DEPTH (mm)

FIG. 19


WATER FLOW RESISTANCE
500
400
300
200
100
0
2.9
0
1
2
3
4
SPIRAL DEPTH (mm)

EXHAUST HEAT RECOVERY DEVICE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a U.S. National Phase Application under 35 U.S.C. 371 of International Application No. PCT/JP2013/004662 filed on Aug. 1, 2013 and published in Japanese as WO 2014/024437 on Feb. 13, 2014. This application is based on and claims the benefit of priority from Japanese Patent Application No. 2012-175156 filed on Aug. 7, 2012 and Japanese Patent Application No. 2013-68046 filed on Mar. 28, 2013. The entire disclosures of all of the above applications are incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to an exhaust heat recovery device used for a vehicle such as an automobile.

BACKGROUND ART

There has been proposed an exhaust heat recovery device for recovering heat acquired by an exhaust gas of an automobile and for utilizing the heat for accelerating the warming up of an engine (for example, see patent document 1). This exhaust heat recovery device has a heating part for exchanging heat between the exhaust gas and a working fluid enclosed in the device and a condensing part for exchanging heat between the working fluid and a cooling water of the engine.

PRIOR ART DOCUMENT

Patent Document

Patent Document 1: JP2007-332857A

By the way, in the exhaust heat recovery device described in the patent document 1 described above, a structure such that a tube in which the working fluid flow is coupled to a header at upper and lower end portions thereof is employed as the heating part. Hence, a difference in linear expansion developed by a rapid temperature change (100 to 900° C.) in the exhaust gas may cause a thermal strain, which may result in breaking a portion in which the tube is fixed in the header.

SUMMARY OF INVENTION

The present disclosure addresses the above issues. Thus, it is an objective of the present disclosure to provide an exhaust heat recovery device that can be restricted from being broken by a thermal strain.

To achieve the objective of the present disclosure, an exhaust heat recovery device in one aspect of the present disclosure includes a heating part, a condensing part, and a storing part. The heating part exchanges heat between heating fluid and working fluid, which is enclosed in the heating part and is capable of being evaporated and condensed, so as to evaporate the working fluid. The heating part includes a tube through which the working fluid flows. An upper end portion of the tube in a vertical direction opens. A lower end portion of the tube in the vertical direction is closed. The condensing part exchanges heat between the working fluid evaporated by the heating part and heated fluid so as to condense the working fluid. The storing part is provided on an upper side of the heating part in the vertical direction and

stores the working fluid condensed by the condensing part. The storing part includes a tube joint part that is joined to the upper end portion of the tube, and a condensed liquid holding part that holds the working fluid condensed by the condensing part.

According to the present disclosure, only the upper side end portion of the tube is joined to the tube joint part and the tube is not constrained at a portion other than the upper side end portion thereof. Therefore, it is possible to restrict a thermal strain from being caused by a difference in linear expansion developed by a rapid temperature change in the heating fluid and hence to restrain a portion in which the tube is fixed in the tube joint part from being broken.

Further, the exhaust heat recovery device is provided with the storing part for storing the working fluid condensed by the condensing part, so the condensed working fluid is brought into contact with the tube joint part to thereby restrict the temperature of the tube joint part from being increased. Further, in the storing part is arranged the condensed liquid holding part for holding the working fluid condensed by the condensing part, so the condensed working fluid can be wetly spread over the entire storing part, that is, over the entire surface of the tube joint part. Hence, even in the case where the temperature of the heating fluid is rapidly increased, a temperature increase in the tube joint part can be restricted, which hence can restrict a thermal strain from being caused and can reliably restrict a portion in which the tube is fixed in the tube joint part from being broken.

In another mode of the present disclosure, the condensed liquid holding part may be eliminated from the exhaust heat recovery device of one mode described above.

BRIEF DESCRIPTION OF DRAWINGS

The above and other objects, features and advantages of the present disclosure will become more apparent from the following detailed description made with reference to the accompanying drawings. In the drawings:

FIG. **1** is a schematic section view to show a sectional construction of an exhaust heat recovery device according to a first embodiment;

FIG. **2** is an exploded perspective view to show the exhaust heat recovery device according to the first embodiment;

FIG. **3** is a section view to show a state in which a valve **5** in the first embodiment is closed;

FIG. **4** is a section view to show a state in which the valve **5** in the first embodiment is opened;

FIG. **5** is a section view taken on a line V-V in FIG. **3**;

FIG. **6** is a section view to show a vicinity of a portion in which a tube **10** is fixed in a core plate in a second embodiment;

FIG. **7** is a section view to show a vicinity of a portion in which a tube **10** is fixed in a core plate in a third embodiment;

FIG. **8** is a schematic section view to show a sectional construction of an exhaust heat recovery device according to a fourth embodiment;

FIG. **9** is a side view to show a tube **10** in a fifth embodiment;

FIG. **10** is a side view to show a tube **10** in a sixth embodiment;

FIG. **11** is a side view to show a tube **10** in a seventh embodiment;

FIG. **12** is a characteristic diagram to show a relationship between the enclosed amount of a working fluid in an eighth embodiment;

FIG. **13** is a characteristic diagram to show a relationship between the enclosed amount of the working fluid and a maximum value of an internal pressure in an eighth embodiment;

FIG. **14** is a characteristic diagram to show a relationship between a boiling performance of a heating part and an upper limit value of the enclosed amount of the working fluid in the eighth embodiment;

FIG. **15** is a perspective view to show a cooling water pipe in a ninth embodiment;

FIG. **16** is a characteristic diagram to show a relationship between a pitch of a groove part and a heat transfer coefficient in the ninth embodiment;

FIG. **17** is a characteristic diagram to show a relationship between the pitch of the groove part and a water flow resistance in the ninth embodiment;

FIG. **18** is a characteristic diagram to show a relationship between a depth of the groove part and a heat transfer coefficient in the ninth embodiment; and

FIG. **19** is a characteristic diagram to show a relationship between the depth of the groove part and the water flow resistance in the ninth embodiment.

EMBODIMENTS FOR CARRYING OUT INVENTION

Hereinafter, embodiments will be described on the basis of the drawings. Here, same parts or equivalent parts in the respective embodiments to be described below will be denoted by the same reference characters in the drawings.

First Embodiment

A first embodiment will be described on the basis of FIG. **1** to FIG. **5**. An exhaust heat recovery device of the present embodiment recovers an exhaust heat of an exhaust gas from an exhaust system of an engine (internal combustion engine) of a vehicle and uses the exhaust heat for warming up the engine. Here, the direction of an arrow directed up and down in FIG. **1** shows a direction of the state in which the exhaust heat recovery device is mounted in the vehicle. Further, in FIG. **2**, for the purpose of making the figure clear, a part of a hydrogen removing device to be described later will be omitted.

As shown in FIG. **1**, the exhaust heat recovery device of the present embodiment is provided with a heating part **1**, a condensing part **2**, and a storing part **3**. The heating part **1** is provided in an exhaust passage **100** in which the exhaust gas of the engine flows. Further, the heating part **1** exchanges heat between a working fluid enclosed in the heating part **1** and the exhaust gas to thereby evaporate the working fluid. Here, the exhaust gas corresponds to a heating fluid of the preset disclosure.

The condensing part **2** is provided on the outside of the exhaust passage **100**. The condensing part **2** exchanges heat between the working fluid evaporated by the heating part **1** and the cooling water of the engine to thereby condense the working fluid. Here, the cooling water corresponds to a heated fluid of the present disclosure.

The storing part **3** is provided on the upper side in a vertical direction of the heating part and on the outside of the exhaust passage **100**. The storing part **3** stores the working fluid condensed by the condensing part **2** and the working fluid condensed by the condensing part **2** flows into the heating part **1** through the storing part **3**. In the present embodiment, the heating part **1**, the storing part **3**, and the condensing part **2** are arranged in this order toward an upper side in the vertical direction.

The heating part **1** has a plurality of tubes **10** in which the working fluid flows and which have their upper end portions in the vertical direction opened and which have their lower end portions in the vertical direction closed. Of each of the tubes **10**, a most portion on the lower side (in the present embodiment, a portion of approximately 80% from a lower end portion thereof) is arranged in the exhaust passage **100** and a portion on the upper side (in the present embodiment, a portion of approximately 20% from an upper end portion thereof) is arranged on the outside of the exhaust passage **100**.

Specifically, an exhaust duct **105** forming the exhaust passage **100** has a through hole **106** formed in an upper face thereof and the tubes **10** are inserted into the exhaust passage **100** from an upper side of the through hole **106**, whereby the tubes **10** are arranged in the exhaust passage **100**.

The upper end portions of the plurality of tubes **10** are joined to a core plate **41** of the storing part **3** to be described later, respectively. The plurality of tubes **10** are not connected to each other except for the portions in which the tubes **10** are joined to the core plate **41**.

In the present embodiment, each of the tubes **10** is formed in the shape of a hollow cylinder having a closed end and has a bottom portion **101** arranged on the lower side. Further, a corner portion formed by the bottom portion **101** and a side portion **102** of the tube **10** is formed in the shape of a circular arc protruding to the outside of the tube **10**. In other words, the corner portion formed by the bottom portion **101** and the side portion **102** of the tube **10** are chamfered in the shape of the circular arc. Further, a wick **103** made of a metal mesh is provided on an inner surface of the tube **10**. The wick **103** is formed in the shape of a net and is arranged on the entire circumference of the inner surface of the tube **10**.

The side portion **102** of a portion arranged in the exhaust passage **100** in the tube **10** has a plurality of fins **11** joined thereto, the plurality of fins **11** accelerating a heat conduction between the exhaust gas and the working fluid. The fins **11** jointed to the plurality of tubes **10** are not connected to each other.

In the present embodiment, each of the fins **11** is formed in the shape of an umbrella. That is, each of the fins **11** has a curved surface **110** shaped like a circular arc in which a portion closer to the lower side is longer in distance from the tube **10** and in which is protruded to the lower side. When the fin **11** is viewed from a longitudinal direction of the tube **10** (in the vertical direction), the fin is formed in the shape of a ring.

On the upper side of the heating part **1**, there is provided a tank part **4** in which the working fluid flows. The tank part **4** has the core plate **41** as a tube joint part which has an upper end side of the tube **10** joined thereto, a tank main body part **42** which constructs a tank interior space together with the core plate **41**, and a partition plate **43** which is provided between the core plate **41** and the tank main body part **42** and which partitions the tank interior space into two portions in the vertical direction.

Of the tank interior space of the tank part **4**, a space formed by the core plate **41** and the partition plate **43** constructs the storing part **3** and a space formed by the tank main body part **42** and the partition plate **43** constructs the condensing part **2**.

The core plate **41** has a tube joint face **410** formed in the shape of a flat plane. Tube joint face **410** has a plurality of communication holes **411** each of which has each of the tubes **10** inserted thereinto. Each of the communication holes **411** of the core plate **41** has a rib **412** formed at the opening edge portion thereof, the rib **412** protruding to the upper side from the tube joint face **410**. The rib **412** is formed when the communication hole **411** is formed in the core plate **41** by burring.

An upper end portion of the tube **10** is arranged on the upper side than the tube joint face **410**, that is, a lower end face in the vertical direction of the core plate **41**. For this reason, the core plate **41** can store the condensed working fluid on the tube joint face **410** thereof.

The storing part **3** is provided with a wick **31** as a condensed liquid holding part for holding the condensed working fluid by a capillary force. The wick **31** is a part which is made of a metal mesh and which can temporarily hold the condensed working fluid in its apertures.

In the condensing part **2** is arranged a cooling water pipe **21** in which the cooling water of the engine flows. The condensing part **2** is constructed in such a way that heat is exchanged between the cooling water flowing in the cooling water pipe **21** and the working fluid flowing outside the cooling water pipe **21**. The working fluid which is cooled and condensed at the surface of the cooling water pipe **21** is made to drop to the lower side of the condensing part **2**. In the present embodiment is employed a pipe which is formed in the shape of a letter U and which is made of stainless steel and the section of which is formed in a circular shape.

The partition plate **43** of the tank part **4** has a first through hole **431** and a second through hole **432** formed therein, each of the first through hole **431** and the second through hole **432** being formed in a circular shape. The storing part **3** and the condensing part **2** communicate with each other via the two through holes **431**, **432**. On an outer circumferential edge portion of the first through hole **431** is provided a wall part **433** extending to an upper side in the vertical direction. The wall part **433** can make the working fluid (water vapor), which flows out of the storing part **3** and is in the state of gas, flow into the condensing part **2** from the upper side in the vertical direction of the condensing part **2**. The second through hole **432** is provided with a valve **5** which opens or closes a passage of the working fluid flowing into the storing part **3** from the condensing part **2**.

As shown in FIG. **3** to FIG. **5**, the valve **5** has a cylindrical base part **51** which is fitted in the second through hole **432**. The base part **51** has flanges **511**, **512** provided at a lower side end portion and an upper side end portion in the vertical direction thereof.

An upper side face of the flange **511** on the lower end side of the base part **51** is joined to a face on the lower side of the partition plate **43**. A clearance is formed between the flange **512** on the upper end side of the base part **51** and the partition plate **43**, so the flange **512** is not in contact with the partition plate **43**.

In the base part **51** is formed a working fluid passage **513** which makes the condensing part **2** communicate with the storing part **3**. The working fluid passage **513** is open at both of a portion, which is between the flange **512** and the partition plate **43** on the side face of the base part **51**, and a face on the lower side of the base part **51**.

In the base part **51** is formed a through hole **514** through which a bar-shaped member **52** extending in the vertical direction passes. To the lower end side of the bar-shape member **52** is connected a valve body **53** for opening and closing the working fluid passage **513**. The valve body **53** is arranged in such a way as to be put into contact with a lower end face of the base part **51**. An upper end side of the bar-shaped member **52** abuts on a diaphragm **54** formed in the shape of a thin film. The valve body **53** is pressed in a direction to close the valve **5** (in an upper direction in FIG. **1**) by the diaphragm **54**.

The diaphragm **54** is arranged on the upper side of the base part **51**. The diaphragm **54** is formed in the shape of a circular disk. The diaphragm **54** is arranged in a diaphragm case **55** and partitions a space in the diaphragm case **55** into a first pressure chamber **551** on the upper side and a second pressure chamber **552** on the lower side.

The diaphragm case **55** is formed of a first diaphragm case **55*a*** and a second diaphragm case **55*b***, each of which is made by pressing a metal plate having a comparatively thin thickness into a predetermined shape. The first and second diaphragm cases **55*a***, **55*b*** are crimped with an outer circumferential face of the diaphragm **54** sandwiched between them, thereby being integrated with each other. Further, the second diaphragm case **55*b*** is joined to an upper end of the base part **51**, whereby the entire diaphragm case **55** is integrally combined with the base part **51**.

The first pressure chamber **551** formed of the diaphragm **54** and the first diaphragm case **55*a*** is always made to communicate with the atmosphere through a through hole, which is not shown, or is always sealed in vacuum, thereby being always held at a constant pressure, so the interior of the first pressure chamber **551** is held at the same pressure as the atmospheric pressure. On the other hand, the second pressure chamber **552** formed of the diaphragm **54** and the second diaphragm case **55*b*** is always made to communicate with the condensing part **2** through a through hole, which is not shown, so the interior of the second pressure chamber **552** is held at the same pressure as the condensing part **2**.

By the construction like this, the valve body **53** is driven by the displacement of the diaphragm **54**, which is caused by a pressure difference between the first pressure chamber **551** and the second pressure chamber **552**, an opening area of the working fluid passage **513** is changed, that is, the working fluid passage **513** is opened or closed. Specifically, as shown in FIG. **3**, in the case where the pressure in the second pressure chamber **552** is larger than the pressure in the first pressure chamber **551**, the valve body **53** is pressed onto a lower end face of the base part **51**, which brings about a state where the working fluid passage **513** is closed, that is, a state where the valve **5** is closed.

On the other hand, as shown in FIG. **4**, in the case where the pressure in the first pressure chamber **551** is larger than the pressure in the second pressure chamber **552**, the valve body **53** is moved in a direction to separate from the lower end face of the base part **51**, which brings about a state where the working fluid passage **51** is opened, that is, a state where the valve **5** is opened. When the valve **5** is opened, as shown by large solid arrows in FIG. **4**, the condensed working fluid flows through the working fluid passage **513** from a side face of the base part **51** and flows out to the storing part **3** from the bottom face of the base part **51**.

In the base part **51** is formed a bypass hole (bypass passage) **56** for making an upper end side of the base part **51** communicate with a lower end side of the base part **51**. In this way, when the valve **5** is closed, the condensed working fluid is held in the condensing part **2**, but in the case where a water level of the condensed working fluid is higher than an upper face of the flange **512** (see a portion shown by broken lines in FIG. **3**), as shown by the large broken arrows in FIG. **3**, the working fluid can be made to flow out to the storing part **3** through the bypass hole **56**.

At this time, since the flange **512** is provided on the upper end portion of the base part **51**, in the case where the water level of the condensed working fluid is not higher than the upper face of the flange **512**, it is possible to restrict the working fluid from flowing into the bypass hole **56** by vibration.

In the present embodiment, a bar-shaped mesh **57** is inserted into the bypass hole **56**. In this way, the flow rate of the working fluid flowing through the bypass hole **56** can be stabilized. Then, by adjusting the dimensions of the mesh **57**, a desired flow rate of working fluid can be acquired.

By the way, in the present embodiment, water is employed as the working fluid and the exhaust heat recovery device is constructed of a chrome-based stainless steel. For this reason, when the exhaust heat recovery device is brought into a high temperature higher than approximately 600° C., the following chemical reaction **1** is caused to generate a hydrogen gas.

$$2Fe+2Cr+3H_2O \rightarrow Fe_2O_3+Cr_2O_3+3H_2 \qquad \text{(Chemical formula 1)}$$

For this reason, the exhaust heat recovery device is provided with a hydrogen removing device **6** for removing the hydrogen gas generated at the high temperature. In the present embodiment, as shown in FIG. **1**, the hydrogen removing device **6** is connected to an upper end portion of the tank part **4** and is constructed in such a way that the hydrogen gas flows in from the upper end portion of the condensing part **2**.

Specifically, in the condensing part **2** is provided a partition wall part **61** extending to an upper side from an upper face of the partition plate **43**. A clearance is formed between an upper end portion of the partition wall part **61** and the tank main body **42**. In the present embodiment, the valve **5**, the first through hole **431**, the partition wall part **61** are arranged in this order.

On a side opposite to the first through hole **431** of the partition wall part **61** in the condensing part **2** is formed a hydrogen gas introduction passage **62** in which the hydrogen gas generated at the high temperature flows. In a portion corresponding to the hydrogen gas introduction passage **62** in the core plate **41** is formed a through hole **413**. To the through hole **413** is joined an upper end portion of a copper oxide receiving part **63** which is formed in the shape of a cylinder which is open only at an upper end thereof. In the copper oxide receiving part **63** is received granular copper oxide (II). The metal oxide receiving part **63** communicates with the condensing part **2** through the hydrogen gas introduction passage **62**.

With this construction, as shown by a broken arrow in FIG. **1**, the hydrogen gas flowing out of the upper end portion of the condensing part **2** flows through the hydrogen gas introduction passage **62** and flows into the copper oxide receiving part **63**. Then, in the copper oxide receiving part **63**, the following chemical reaction **2** is caused.

$$3CuO+3H_2 \rightarrow 3Cu+3H_2O \qquad \text{(Chemical formula 2)}$$

In this way, in the copper oxide receiving part **63**, the hydrogen reacts with the copper oxide (II) to generate copper and water, so the hydrogen can be removed.

By the way, the exhaust heat recovery device is provided with a heat guard **7** as a heat conduction limiting member for limiting a heat conduction from the exhaust gas flowing through the exhaust passage **100** of the heating part **1** to the working fluid stored in the storing part **3**. The heat guard **7** is arranged between the heating part **1** and the storing part **3**.

In more detail, a section when the heat guard **7** is viewed from a direction orthogonal to the vertical direction is formed nearly in the shape of a letter C which is open on the upper side. That is, the heat guard **7** is constructed of a bottom part **71** formed in a flat plane perpendicular to the vertical direction, a wall part **72** bent in nearly perpendicularly from the outer circumferential portion of the bottom part **71** and extended to the upper side, and a flange part **73** bent nearly perpendicularly from the wall part **72** and extended in a direction perpendicular to the vertical direction.

The flange part **73** of the heat guard **7** is joined to the outer circumferential edge portion of the core plate **41**. The heat guard **7** is in contact with the core plate **41** only at the flange part **73** and a space (hereinafter also referred to as a heat guard space **74**) is formed among the bottom part **71** and the core plate **41** and the core plate **41**.

In the bottom part **71** of the heat guard **7** are formed tube through holes **711** into which the tubes **10** are inserted respectively. An inside diameter of the tube through hole **711** is formed in a slightly larger size than an outer diameter of the tube **10**. For this reason, the tube **10** is not in contact with the tube through hole **711** in the state where the tube **10** is inserted into the tube through hole **711**.

Further, the bottom part **71** of the heat guard **7** is formed in a shape corresponding to the through hole **106** of the exhaust duct **105**, that is, in a shape capable of closing the through hole **106**. The heat guard **7** is joined to the exhaust duct **105** in the state where the bottom part **71** closes the through hole **106** of the exhaust duct **105**. Hence, it can be also said that the exhaust passage **100** is formed of the exhaust duct **105** and the bottom part **71** of the heat guard **7**.

Further, a heating through hole **712** is formed at a portion opposite to the copper oxide receiving part **63** in the bottom part **71** of the heat guard **7**. In this way, the exhaust gas flowing through the exhaust passage **100** flows into the heat guard space **74** through the heating through hole **712**. At this time, the copper oxide receiving part **63** can be heated by the heat acquired by the exhaust gas. In this regard, the exhaust gas flowing through the exhaust passage **100** flows into the heat guard space **74** also from the tube through hole **711**.

Since the heat guard **7** is provided with the heating through hole **712** and the tube through hole **711**, the exhaust gas flows not only through the exhaust passage **100** but also through the heat guard space **74**. Hence, the exhaust passage **100** and the heat guard space **74** correspond to a heating fluid passage of the present disclosure.

Next, the action of the exhaust heat recovery device of the present embodiment will be described. At the time of heat recovery when the exhaust heat recovery device recovers the heat of the exhaust gas, the valve **5** is opened. At this time, in the tube **10** of the heating part **1**, the working fluid is heated by the exhaust gas and hence is evaporated, thereby flowing out to the storing part **3** from the top end portion of the tube **10**. The vapor of the working fluid flowing out of the top end portion of the tube **10** flows into the condensing part **2** through the storing part **3** and the first through hole **431** of the partition plate **43**. The vapor of the working fluid flowing into the condensing part **2** exchanges heat with the cooling water flowing in the cooling water pipe **21** and hence is condensed on the surface of the cooling water pipe **21**, thereby being brought into liquid and dropped on the partition plate **43**.

The liquid working fluid dropped on the partition plate **43** flows through the working fluid passage **513** in the valve **5** and is returned onto the core plate **41** of the storing part **3**. The liquid working fluid flowing into the storing part **3** is stored on the core plate **41**. Then, when the water level of the working fluid becomes higher than the top end portion of the rib **412**, the working fluid again flows into the tube **10** from the top end portion of the tube **10**.

On the other hand, at the time of heat interruption when the exhaust heat recovery device does not recover the heat of the exhaust gas, the valve **5** is closed. At this time, the working fluid condensed on the surface of the cooling water pipe **21** remains on the partition plate **43**. Then, when the water level of the working fluid remaining on the partition plate **43** becomes higher than the upper face of the flange **512**, the working fluid flows into the storing part **3** through the bypass hole **56**.

In the exhaust heat recovery device of the present embodiment, only the upper side end portion of the tube **10** is joined to the core plate **41** and the tube **10** is not constrained at a portion other than the upper side end portion thereof. In this way, it is possible to restrict a portion in which the tube **10** is rooted in the core plate **41** from being broken by a thermal strain developed by a difference in linear expansion caused by a rapid temperature change in the exhaust gas.

Further, the upper end portion of the tube **10** is arranged on the upper side than the tube joint face **410** of the core plate **41** and there is provided the storing part **3** for storing the working fluid condensed in the condensing part **2**, so a specified amount of liquid working fluid can be made to exist on the tube joint face **410** of the core plate **41**. In this way, the condensed working fluid can be brought into contact with the core plate **41** to thereby restrict a temperature increase in the core plate **41**. Still further, since the exhaust heat recovery device is provided the storing part **3**, when the exhaust heat recovery device usually recovers the exhaust heat, the exhaust heat recovery device can distribute the working fluid uniformly to the respective tubes **10** irrespective of the position in which the valve **5** is provided.

Still further, since the wick **31** which holds the working fluid condensed in the condensing part **2** by the capillary force is arranged in the storing part **3**, the liquid working fluid can be wetly spread on the entire surface of the core plate **41**. Hence, even in the case where the temperature of the exhaust gas is rapidly increased, a temperature increase in the core plate **41** can be restricted, which hence makes it possible to restrict a thermal strain from being developed and to reliably restrict the portion in which the tube **10** is fixed to the core plate **41** from being broken by the thermal strain.

Still further, since the storing part **3** has the wick **31** arranged therein, the wick **31** can restrict the liquid working fluid existing on the core plate **41** from being moved to one side or jumped by vibration or by the inclination of the exhaust heat recovery device to thereby make the working fluid flow into the tube **10** in the state where the specified amount of working fluid does not exist on the core plate **41**.

By the way, in the exhaust heat recovery device having the valve **5** like the present embodiment, when load is high and a cooling water temperature is high, the valve **5** needs to be throttled to reduce the flow rate of the working fluid circulated in the exhaust heat recovery device, thereby reducing the amount of heat to be recovered. However, when the cooling water temperature is high, the amount of circulation of the working fluid might be excessively reduced by the valve **5** to thereby eliminate the working fluid from being on a part of the core plate **41** (to thereby dry out the core plate **41**). In this case, a local temperature distribution will be formed on the core plate **41** and a strained amplitude, which is caused by a temperature difference between at the time when the core plate **41** is dried out and at the time when the water level of the working fluid is high, will extremely reduce the life of the exhaust heat recovery device.

In contrast to this, in the present embodiment, there is provided the bypass hole **56** which makes the working fluid condensed in the condensing part **2** bypass the valve **5** to thereby introduce the working fluid into the storing part **3**. In this way, even when the valve **5** is closed, in the case where the water level of the working fluid on the partition plate **43** is higher than a given level, the working fluid can be returned to the storing part **3** through the bypass hole **56**. For this reason, it is possible to always make the liquid working fluid exist on the core plate **41** and hence to restrict a local temperature distribution from being formed on the core plate **41**.

Further, in the present embodiment, the heat guard **7** for restricting the heat conduction from the exhaust gas of the heating part **1** to the working fluid in the storing part **3** is provided between the heating part **1** and the storing part **3**. In this way, it is possible to restrict the core plate **41** from being heated with the heat acquired by the exhaust gas to thereby increase the temperature of the core plate **41**.

Still further, in the present embodiment, the fins **11** provided on the plurality of tubes **10** are constructed in such a way as not to be connected to each other. In this way, it is possible to restrict the tubes **10** from being constrained at a portion other than the upper side end portion thereof and hence to restrict a thermal strain from being developed by a difference in linear expansion caused by a rapid temperature change in the exhaust gas.

By the way, when the temperature of the tube **10** is lowered, the fins **11** joined to the tube **10** are pulled inside (to the side of the tube **10**) and hence the fins are deformed. In addition, when the fins **11** are once deformed, even if the temperature of the tube **10** is made higher, the deformed fins **11** cannot be returned to their original shapes.

In contrast to this, in the present embodiment, each of the fins **11** has a curved face **110** which is protruded to the lower side and which is shaped like a circular arc. In this way, even if the temperature of the tube **10** is lowered to thereby apply a force pulling inside to the fin **11**, the curved face **110** shaped like the circular arc can absorb the deformation of the fun **11** and hence can restrict the fin **11** from being deformed.

Further, in the present embodiment, the tube **10** is formed in the shape of a hollow cylinder having a closed end and a corner portion formed of the side part **102** and the bottom part **101** is formed in the shape a circular arc. In this way, it is possible to secure the pressure resistance of the tube **10** and to restrict the thermal strain from being developed in the tube **10**.

By the way, like the present embodiment, the exhaust heat recovery device provided with the hydrogen removing device **6** for removing the hydrogen gas generated at the high temperature has the copper oxide receiving part **63** in which copper oxide (II) for removing the hydrogen is enclosed. Since a hydrogen removing reaction by the copper oxide (II) (see the chemical formula 2 described above) is not caused at a high temperature not less than 300° C., the copper oxide receiving part **63** is usually arranged in the heating part **1** in which the exhaust gas flows. However, under the circumstance of a high temperature not less than 600° C., an oxidation phenomenon of the stainless steel is accelerated with the copper oxide (II) as a medium, which hence presents a problem that the tube **10** of the heating part **1** is oxidized and corroded.

In contrast to this, in the present embodiment, the upper end portion of the copper oxide receiving part **63** is connected to the core plate **41** and the copper oxide receiving part **63** is arranged in the heat guard space **74** in which the exhaust gas flows. According to this, since the copper oxide receiving part **63** is arranged at the portion in which the exhaust gas flows, the copper oxide receiving part **63** can be heated with the heat acquired by the exhaust gas and hence the hydrogen removing reaction by the copper oxide (II) can be reliably caused. On the other hand, the upper end portion of the copper oxide receiving part **63** is connected to the core plate **41** which has the liquid working fluid stored on the upper face thereof and which is at a comparatively low temperature, so the copper oxide receiving part **63** can be restricted from being brought to an abnormally high temperature. Hence, it is possible to remove the hydrogen gas and to restrict the abnormal oxidization phenomenon of the stainless steel at the same time.

In particular, the copper oxide receiving part **63** is arranged in the heat guard space **74** and the heating through hole **712** is formed in the heat guard space **74** to thereby introduce the exhaust gas into the heat guard space **74**, so it is possible to prevent the main stream of the exhaust gas of high temperature from directly hitting the copper oxide receiving part **63**. In this way, it is possible to restrict the temperature of the copper oxide receiving part **63** from being changed by the flow rate of the exhaust gas. Hence, even when the exhaust heat recovery device is mounted in a vehicle having a large displacement, it is possible to remove the hydrogen gas and to restrict the abnormal oxidization phenomenon of the stainless steel at the same time.

Further, the present embodiment is constructed in such a way that the hydrogen gas introduction passage **62** is connected to the upper side of the condensing part **2** to thereby make the hydrogen gas flow into the hydrogen gas removing device **6** from the upper end portion of the condensing part **2**. In this way, it is possible to make the hydrogen gas which is lighter than the working fluid flow into the copper oxide receiving part **63** through the hydrogen gas introduction passage **62** to thereby restrict the working fluid from flowing into the copper oxide receiving part **63**.

Second Embodiment

Next, a second embodiment will be described on the basis of FIG. **6**. As shown in FIG. **6**, in the exhaust heat recovery device of the present embodiment, the upper end portion of the tube **10** is arranged on the upper side of the core plate **41**.

The communication hole **411** of the core plate **41** has a rib **414** formed on an opening edge portion thereof, the rib **414** protruding to a lower side in the vertical direction. The rib **414** is formed at the time when the communication hole **411** is formed in the core plate **41** by burring. The tube **10** has a wick **104** provided on an upper end face thereof, the wick **104** being made of metal in such a way as to connect a wick **103** arranged on an inner face of the tube **10** and a wick **31** arranged on the core plate **41**.

According to the present embodiment, the wick **104** is provided on the upper end portion of the tube **10**, so when the exhaust heat recovery device usually recovers the exhaust heat, the exhaust heat recovery device can suck only the working fluid overflowing from the wick **31** into the tube **10** by the wick **104**. Hence, it is possible to restrict the exhaust heat recovery device from making the working fluid flow into the tube **10** more than necessary to thereby eliminate the working fluid on the core plate **41** (to thereby dry out the core plate **41**).

Third Embodiment

Next, a third embodiment will be described on the basis of FIG. **7**. The third embodiment is different from the second embodiment described above in the shape of the upper end portion of the tube **10**.

As shown in FIG. **7**, the upper end portion of the tube **10** is formed in a reverse flow restricting portion **107** which is curved in the shape of a circular arc in such a way as to expand to the inside of the tube **10**. Since the reverse flow restricting portion **107** is provided, in the case where the exhaust heat is not recovered, the reverse flow restricting portion **107** can restrict the condensed working fluid stored in the storing part **3** from flowing into the tube **10** by the acceleration of the vehicle or the like.

Fourth Embodiment

Next, a fourth embodiment of the present embodiment will be described on the basis of FIG. **8**. The fourth embodiment is different from the first embodiment described above in that the hydrogen removing device **6** is constructed as a part separate from the tank part **4**. Here, the fins **11** will be omitted in FIG. **8**.

As shown in FIG. **8**, the copper oxide receiving part **63** of the hydrogen removing device **6** is arranged on the outside of the exhaust duct **105** (on the side of the outside air). Further, one face of the copper oxide receiving part **63** is joined to an outer surface of the exhaust duct **105**. In this way, a part of the copper oxide receiving part **63** is joined to the exhaust passage **100** via the exhaust duct **105**. Further, of the copper oxide receiving part **63**, a portion which is not in contact with the outer surface of the exhaust duct **105** is in contact with the outside air.

To the copper oxide receiving part **63** is connected one end portion of a hydrogen gas introduction pipe **64** which forms the hydrogen gas introduction passage **62**. The other end portion of the hydrogen gas introduction pipe **64** is connected to the condensing part **2** of the tank part **4**. In other words, the copper oxide receiving part **63** and the condensing part **2** are connected to each other via the hydrogen gas introduction pipe **64**. In this way, the hydrogen gas which flows out of the condensing part **2** flows through the hydrogen gas introduction pipe **64** and flows into the copper oxide receiving part **63**.

According to the present embodiment, the copper oxide receiving part **63** is arranged at a portion in contact with the exhaust passage **100** in which the exhaust gas flows, so the copper oxide receiving part **63** can be heated with the heat acquired by the exhaust gas and hence the hydrogen removing reaction by the copper oxide (II) can be reliably caused. On the other hand, a portion which is not in contact with the exhaust passage **100** in the copper oxide receiving part **63** is brought into contact with the outside air, so the copper oxide receiving part **63** can be restricted from being made abnormally high temperature. Hence, it is possible to remove the hydrogen gas and to restrict the abnormal oxidization phenomenon of the stainless steel at the same time.

Fifth Embodiment

Next, a fifth embodiment of the present embodiment will be described on the basis of FIG. **9**. The fifth embodiment is different from the first embodiment described above in the construction of the fin **11**.

As shown in FIG. **9**, the fins **11** of the present embodiment are formed by plastically working an outside surface of the tube **10** in a spiral shape. According to this, it is possible to eliminate the need for providing separate members as fins, so the fins **11** can be provided on the outside surface of the tube **10** with the number of parts reduced. Further, the fins are formed in the spiral shape, so the fins can improve a heat transfer coefficient.

Sixth Embodiment

Next, a sixth embodiment of the present embodiment will be described on the basis of FIG. **10**. The sixth embodiment is different from the first embodiment described above in the construction of the fin **11**.

As shown in FIG. **10**, the fins **11** of the present embodiment are formed by knurling the outside surface of the tube **10**. According to this, it is possible to eliminate the need for providing separate members as fins, so the fins **11** can be provided on the outside surface of the tube **10** with the number of parts reduced. Further, the fins **11** are formed by knurling, so the fins can improve the heat transfer coefficient.

Seventh Embodiment

Next, a seventh embodiment of the present embodiment will be described on the basis of FIG. **11**. The seventh embodiment is different from the first embodiment described above in the construction of the tube **10** and the fin **11**.

As shown in FIG. **11**, the tube **10** of the present embodiment has a spiral groove part **108** formed on the inside surface thereof. The groove part **108** functions as a wick for sucking the liquid working fluid stored in the storing part **3** by a capillary force and for supplying the liquid working fluid to the tube **10**.

According to the present embodiment, without providing a wick which is a part separate from the tube **10**, it is possible to suck the liquid working fluid stored in the storing part **3** by the capillary force and to supply the liquid working fluid to the tube **10**. For this reason, it is possible to reliably supply the working fluid to the tube **10** from the storing part **3** with the number of parts reduced.

Eighth Embodiment

Next, an eighth embodiment of the present embodiment will be described on the basis of FIG. **12** to FIG. **14**. The eighth embodiment is different from the first embodiment described above in that the amount of working fluid (volume of working fluid) enclosed in the exhaust heat recovery device is specified.

The valve **5** of the present embodiment is constructed in such a way that when the temperature of the working fluid flowing through the working fluid passage **513** which makes the condensing part **2** communicate with the storing part **3** becomes not less than a predetermined standard temperature, the condensed working fluid passage **513** is closed.

Specifically, as is the case with the first embodiment, a mechanically operated valve which senses the pressure of the working fluid enclosed therein to thereby operate the diaphragm **54** can be employed as the valve **5**. The relationship between the temperature and the pressure of the working fluid is always 1 to 1, so when the pressure of the working fluid is sensed, the temperature of the working fluid can be indirectly sensed. In this regard, it is also recommended to employ a working fluid temperature response valve constructed of a mechanical mechanism in which a valve body **53** is displaced by a thermo-wax (temperature sensing member) whose volume is changed by the temperature to thereby open or close the working fluid passage **513**.

Here, it is assumed as follows: a heating-part heat transfer area that is the total sum of heat transfer areas between the exhaust gas and the working fluid in the heating part **1** is F_g; a heating-part volume that is the total sum of the volumes of parts in which the working fluid flows (total sum of the volumes of the plurality of tubes **10**) in the heating part **1** is V_g; a heat transfer coefficient of the exhaust gas is α_g; a condensing-part heat transfer area that is the total sum of heat transfer areas between the cooling water and the working fluid in the condensing part **2** is F_w, a condensing-part volume that is the volume of a part in which the working fluid flows in the condensing part **2** is V_w; a heat transfer coefficient of the cooling water is α_w; and the volume of the storing part **3** is V_c.

As shown in FIG. **12**, when the enclosed amount of the working fluid is smaller than V_w+0.4 V_g, that is, the total volume of the condensing-part volume V_w and 40% of the heating-part volume V_g, an exhaust heat recovery performance Q_w is decreased. For this reason, in the present embodiment, the lower limit value M_1 of the enclosed amount of the working fluid is set in such a way as to satisfy the relationship shown by the following mathematical formula 1.

$$M_1 = V_w + 0.4V_g \quad \text{(Mathematical formula 1)}$$

Here, in exhaust heat recovery devices of various specifications in which a ratio of a boiling performance ($\alpha_g F_g$) of the heating part **1** to a condensing performance ($\alpha_w F_w$) of the condensing part **2** is different from each other, the relationship between a maximum value Pr_max of an internal pressure and the enclosed amount M of the working fluid of the exhaust heat recovery device when the exhaust heat recovery device is mounted in the vehicle was calculated by an experiment. The result of the experiment will be shown in FIG. **13**.

Here, the exhaust heat recovery device of the present embodiment is constructed of stainless steel. The pressure resistant strength of the stainless steel is approximately 500 kPa, so a working fluid volume M_2 in which the maximum value Pr_max of the internal pressure becomes 500 kPa was found in each of the exhaust heat recovery devices. If a working fluid amount enclosed in each of the exhaust heat recovery devices is not more than M_2, the internal pressure of the exhaust heat recovery device is not more than 500 kPa.

The relationship between the boiling performance ($\alpha_g F_g$) of the heating part **1** and the working fluid amount M_2 found from FIG. **13** will be shown in FIG. **14**. An approximating equation passing plotted points shown in FIG. **14** is shown by

$$M_2 = V_w/2 + V_c + 150\exp(-11\times\alpha_g F_g/\alpha_w F_w)$$

For this reason, in the present embodiment, an upper limit value M_2 of the enclosed amount of the working fluid is set in such a way as to satisfy the relationship shown by the following mathematical formula 2.

$$M_2 = V_w/2 + V_c + 150\exp(-11\times\alpha_g F_g/\alpha_w F_w) \quad \text{(Mathematical formula 2)}$$

As described above, when the lower limit value M_1 of the volume of the working fluid enclosed in the exhaust heat recovery device is set in such a way as to satisfy the relationship shown by the mathematical formula 1 described above, the exhaust heat recovery performance Q_w can be secured.

Further, when an upper limit value M_2 of the volume of the working fluid enclosed in the exhaust heat recovery device is set in such a way as to satisfy the relationship shown by the mathematical formula 2 described above, even if the vehicle is brought into any state (is accelerated or changed in speed), a maximum value of variation in the internal pressure can be control to a value not more than 500 kPa. Hence, the pressure resistance of the exhaust heat recovery device can be secured.

As described above, the enclosed amount of the working fluid specified in the present embodiment is determined so as to restrict the internal pressure from being abnormally increased. For this reason, the mechanically operated valve which senses the pressure of the working fluid enclosed therein to thereby operate the diaphragm **54** can be employed as the valve **5** in terms of response.

Ninth Embodiment

Next, a ninth embodiment of the present embodiment will be described on the basis of FIG. **15**~FIG. **19**. The ninth embodiment is different from the first embodiment described above in the shape of the cooling water pipe **21**.

As shown in FIG. **15**, the cooling water pipe **21** of the present embodiment has a spiral groove part **21***a* formed on the surface thereof. In the present embodiment, the groove part **21***a* is formed on a portion other than a bent portion **21***b* in which a cooling water passage is bent in the cooling water pipe **21**. In the present embodiment, a pipe having an outer diameter of 10 mm or more to 30 mm or less is used as the cooling water pipe **21**.

In this way, when the cooling water pipe **21** has the spiral groove part **21***a* formed on the surface thereof, the condensing performance can be improved without increasing a space in which the cooling water pipe **21** is mounted.

By the way, when the spiral pitch of the groove part **21***a* is set at 2 mm or more to 18 mm or less, as shown in FIG. **16**, a heat transfer coefficient α in the cooling water pipe **21** can be made larger than 200 W/m^2K, so the heat transfer coefficient α can be improved. At this time, as shown in FIG. **17**, in the case where the spiral pitch of the groove part **21***a* is set at 2 mm or more to 18 mm or less, the water flow resistance of the cooling water pipe **21** can be made 300 or less, that is, the water flow resistance of the cooling water pipe **21** can be reduced.

Hence, when the spiral pitch of the groove part **21***a* is set at 2 mm or more to 18 mm or less, the heat transfer coefficient α in the cooling water pipe **21** can be improved and the water flow resistance of the cooling pipe **21** can be reduced. In this way, the performance of the condensing part **2** can be reliably improved.

Further, as shown in FIG. **18**, when the depth of the groove part **21***a* is set at 2.0 mm or more, the heat transfer coefficient α in the cooling water pipe **21** can be made larger than 200 W/m^2K and hence the heat transfer coefficient α can be improved.

On the other hand, as shown in FIG. **19**, as the depth of the groove part **21***a* is larger, the water flow resistance of the cooing water pipe **21** becomes larger. Here, when the depth of the groove part **21***a* is set at 2.9 mm or less, the water flow resistance of the cooing water pipe **21** can be made 300 or less, so the water flow resistance of the cooing water pipe **21** can be reduced.

Hence, when the depth of the groove part **21***a* is set at 2.0 mm or more to 2.9 mm or less, the heat transfer coefficient α in the cooling water pipe **21** can be improved and the water flow resistance of the cooing water pipe **21** can be reduced. In this way, the performance of the condensing part **2** can be surely improved.

The present disclosure is not limited to the embodiments described above but can be variously modified in the following manner within a scope not departing from the gist of the present disclosure.

(1) In the embodiments described above has been described an example in which the wick **31** is employed as the condensed liquid holding part. However, it is not limited to this but, for example, when a groove part is formed on the tube joint face **410** of the core plate **41**, the groove part formed on the tube joint face **410** can function as the condensed liquid holding part.

(2) In the present embodiments described above has been described an example in which the exhaust heat recovery device is constructed of the chrome-based stainless steel, but a material constructing the exhaust heat recovery device is not limited to the this. For example, if there is any other material which reacts with the water of the working fluid to thereby generate hydrogen when it is heated, the exhaust heat recovery device may be constructed of the material.

(3) In the embodiment described above has been described an example in which the mesh **57** is arranged in the bypass hole **56** of the valve **5**. However, it is not limited to this, but the bypass hole **56** of the valve **5** does not need to be provided with the mesh **57**.

(4) In the embodiments described above (except for the fourth embodiment) has been described an example in which the hydrogen removing device **6** is formed integrally with the tank part **4**, that is, the partition wall part **61** is provided in the tank part **4** to thereby form the hydrogen gas introduction passage **62**. However, it is not limited to this but the hydrogen removing device **6** may be constructed as a part separate from the tank part **4** to thereby introduce the hydrogen gas from the upper end portion of the condensing part **2** of the tank part **4**.

(5) In the embodiments described above has been described an example in which the copper oxide (II) is employed as the metal oxide arranged in the hydrogen removing device **6**. However, it is not limited to this but other metal oxide may be employed.

(6) In the embodiments described above (except for the fifth embodiment and the sixth embodiment) has been described an example in which the tube **10** is formed in the shape of the hollow cylinder having the closed end and in which the corner portion formed of the bottom portion **101** and the side face portion **102** of the tube **10** is formed in the shape of the circular arc protruding to the outside of the tube **10**. However, the shape of the tube **10** is not limited to this. For example, the corner portion formed of the bottom portion **101** and the side face portion **102** of the tube **10** may be formed in a right angle or the tube **10** may be formed in the other shape of such as a hollow ellipsoidal cylinder having a closed end.

(7) In the embodiments described above has been described an example in which the fin **11** is formed in the shape of the umbrella. However, it is not limited to this but, for example, the fin **11** may be formed in the shape of a flat plate.

(8) In the embodiments described above (except for the seventh embodiment) has been described an example in which the wick **103** is arranged in the tube **10**. However, it is not limited to this but the wick **103** does not need to be arranged in the tube **10**. Further, a wick made of a metal mesh may be arranged on the upper end portion of the tube **10** in such a way as to connect the wick **103** in the tube **10** to the wick **31** on the core plate **41**.

(9) In the embodiments described above has been described an example in which the heat guard **7** is provided between the heating part **1** and the storing part **3**. However, it is not limited to this but the heat guard **7** does not need to be provided.

(10) In the embodiments described above has been described an example of the construction in which the heating through hole **712** and the tube through hole **711** are formed in the heat guard **7** to thereby make the exhaust gas flow into the heat guard space **74**. However, it is not limited to this but the heat guard **7** may be constructed in such a way that the exhaust gas does not flow into the heat guard space **74**.

(11) In the embodiments described above has been described an example in which the flange **512** is provided on the upper end portion of the base part **51** in the valve **5**. However, it is not limited to this but the valve **5** does not need to be provided with the flange **512**.

(12) In the eighth embodiment described above has been described an example in which the working fluid temperature response valve of a mechanical type is employed as the valve **5**. However, the valve **5** is not limited to this but, for example, an electromagnetic valve whose operation is controlled on the basis of a control voltage outputted from a control device may be employed as the valve **5**. In this case, the exhaust heat recovery device is provided with a temperature sensor for sensing the temperature of the working fluid. Then, the control device controls the operation of the electromagnetic valve on the basis of the temperature of the working fluid sensed by the temperature sensor.

(13) In the embodiments described above has been described an example in which the wick made of the metal mesh formed in the shape of a mesh is employed as the wick **103**. However, it is not limited to this but a coil wick formed in the shape of a coil (spiral) may be used as the wick **103**.

While the present disclosure has been described with reference to embodiments thereof, it is to be understood that the disclosure is not limited to the embodiments and constructions. The present disclosure is intended to cover various modification and equivalent arrangements. In addition, while the various combinations and configurations, other combinations and configurations, including more, less or only a single element, are also within the spirit and scope of the present disclosure.

The invention claimed is:

1. An exhaust heat recovery device comprising:

a heating part that exchanges heat between heating fluid and working fluid, which is enclosed in the heating part and is capable of being evaporated and condensed, so as to evaporate the working fluid,

the heating part includes a tube through which the working fluid flows;

an upper end portion of the tube in a vertical direction opens; and

a lower end portion of the tube in the vertical direction is closed;

a condensing part that exchanges heat between the working fluid evaporated by the heating part and heated fluid so as to condense the working fluid; and

a storing part located outside of the tube is provided on an upper side of the heating part in the vertical direction and stores the working fluid condensed by the condensing part, the storing part includes a tube joint part that is joined to the upper end portion of the tube.

2. An exhaust heat recovery device comprising:

a heating part that exchanges heat between heating fluid and working fluid, which is enclosed in the heating part and is capable of being evaporated and condensed, so as to evaporate the working fluid,

the heating part includes a tube through which the working fluid flows;

an upper end portion of the tube in a vertical direction opens; and

a lower end portion of the tube in the vertical direction is closed;

a condensing part that exchanges heat between the working fluid evaporated by the heating part and heated fluid so as to condense the working fluid;

a storing part located outside of the tube is provided on an upper side of the heating part in the vertical direction and stores the working fluid condensed by the condensing part, the storing part includes:

a tube joint part that is joined to the upper end portion of the tube;

a condensed working fluid passage that introduces the working fluid condensed by the condensing part to the storing part; and

a valve that opens or closes the condensed working fluid passage and is configured to close the condensed working fluid passage when temperature of the working fluid flowing through the condensed working fluid passage reaches a predetermined standard temperature or higher.

3. The exhaust heat recovery device according to claim **2**, wherein the upper end portion of the tube is arranged on a vertically upper side of a lower end surface of the tube joint part in the vertical direction.

4. The exhaust heat recovery device according to claim **2**, further comprising:

a bypass passage through which the working fluid condensed by the condensing part flows to bypass the valve into the storing part.

5. The exhaust heat recovery device according to claim **2**, wherein:

the tube includes a fin that accelerates a heat transfer between the heating fluid and the working fluid; and

the fin is formed by plastically working an outside surface of the tube into a spiral shape.

6. The exhaust heat recovery device according to claim **2**, wherein:

the tube includes a fin that accelerates a heat transfer between the heating fluid and the working fluid; and

the fin is formed by knurling an outside surface of the tube.

7. The exhaust heat recovery device according to claim **2**, wherein:

the tube includes a groove part that is formed on an inside surface of the tube; and

the groove part absorbs the working fluid stored in the storing part by capillary force to supply the working fluid to the tube.

8. The exhaust heat recovery device according to claim **2**, further comprising a heat conduction limiting member between the heating part and the storing part, wherein the heat conduction limiting member limits a heat conduction from the heating fluid for the heating part to the working fluid in the storing part.

9. The exhaust heat recovery device according to claim **2**, wherein:

the tube is formed in a shape of a hollow cylinder having a closed end, and includes a side surface portion, a bottom portion, and a corner portion between the side surface portion and the bottom portion; and

the corner portion is formed in a shape of a circular arc.

10. The exhaust heat recovery device according to claim **2**, wherein M_1, which is a lower limit value of a volume of the enclosed working fluid, and M_2, which is an upper limit value of the volume of the enclosed working fluid are set to satisfy a relationship expressed by the following first mathematical formula and second mathematical formula:

$$M_1=V_w+0.4V_g; \quad \text{(first mathematical formula)}$$

and

$$M_2=V_w/2+V_c+150\exp(-11\times\alpha_g F_g/\alpha_w F_w); \quad \text{(second mathematical formula)}$$

where:

F_g is a total sum of a heat transfer area between the heating fluid and the working fluid in the heating part;

V_g is a volume of a part of the heating part through which the working fluid flows;

α_g is a heat transfer coefficient of the heating fluid;

F_w is a total sum of a heat transfer area between the heated fluid and the working fluid in the condensing part;

V_w is a volume of a part of the condensing part in which the working fluid flows;

α_w is a heat transfer coefficient of the heated fluid; and

V_c is a volume of the storing part.

11. The exhaust heat recovery device according to claim **2**, wherein the storing part includes a condensed liquid holding part that holds the working fluid condensed by the condensing part.

12. The exhaust heat recovery device according to claim **2**, wherein:

the tube is one of a plurality of tubes;

the plurality of tubes includes fins respectively;

the fins accelerate a heat conduction between the heating fluid and the working fluid; and

the fins are not connected to each other.

13. The exhaust heat recovery device according to claim **12**, wherein each of the fins includes a curved surface having a shape of a circular arc projecting toward a lower side in the vertical direction.

14. The exhaust heat recovery device according to claim **2**, wherein:

the working fluid is water; and

the heating part, the condensing part, and the storing part are configured from a material that reacts with the working fluid to generate hydrogen gas when heated, the exhaust heat recovery device further comprising:

a heating fluid passage through which the heating fluid flows; and

a metal oxide receiving part in which metal oxide is enclosed and into which the hydrogen gas flows, wherein:

the metal oxide receiving part communicates with the condensing part; and

at least a part of the metal oxide receiving part is arranged in the heating fluid passage.

15. The exhaust heat recovery device according to claim **14**, further comprising a heat conduction limiting member between the heating part and the storing part, wherein:

the heat conduction limiting member limits a heat conduction from the heating fluid for the heating part to the working fluid in the storing part; and

the metal oxide receiving part is connected to the tube joint part and is arranged between the tube joint part and the heat conduction limiting member.

16. The exhaust heat recovery device according to claim **14**, wherein a part of the metal oxide receiving part is in contact with the heating fluid passage and another part of the metal oxide receiving part is in contact with outside air.

17. The exhaust heat recovery device according to claim **14**, further comprising a hydrogen gas introduction passage that is connected to an upper side of the condensing part in the vertical direction and introduces the hydrogen gas into the metal oxide receiving part.

18. An exhaust heat recovery device comprising:

a heating part that exchanges heat between heating fluid and working fluid, which is enclosed in the heating part and is capable of being evaporated and condensed, so as to evaporate the working fluid,

the heating part includes a tube through which the working fluid flows;

an upper end portion of the tube in a vertical direction opens; and

a lower end portion of the tube in the vertical direction is closed;

a condensing part that exchanges heat between the working fluid evaporated by the heating part and heated fluid so as to condense the working fluid;

a storing part that is provided on an upper side of the heating part in the vertical direction and stores the working fluid condensed by the condensing part, the storing part includes:

a tube joint part that is joined to the upper end portion of the tube;

a condensed working fluid passage that introduces the working fluid condensed by the condensing part to the storing part;

a valve that opens or closes the condensed working fluid passage and is configured to close the condensed working fluid passage when temperature of the working fluid flowing through the condensed working fluid passage reaches a predetermined standard temperature or higher; and

a bypass passage through which the working fluid condensed by the condensing part flows to bypass the valve into the storing part.

19. The exhaust heat recovery device according to claim **18**, wherein:

the working fluid is water; and

the heating part, the condensing part, and the storing part are configured from a material that reacts with the working fluid to generate hydrogen gas when heated, the exhaust heat recovery device further comprising:

a heating fluid passage through which the heating fluid flows; and

a metal oxide receiving part in which metal oxide is enclosed and into which the hydrogen gas flows, wherein:

the metal oxide receiving part communicates with the condensing part; and

at least a part of the metal oxide receiving part is arranged in the heating fluid passage.

20. The exhaust heat recovery device according to claim **19**, further comprising a heat conduction limiting member between the heating part and the storing part, wherein:

the heat conduction limiting member limits a heat conduction from the heating fluid for the heating part to the working fluid in the storing part; and

the metal oxide receiving part is connected to the tube joint part and is arranged between the tube joint part and the heat conduction limiting member.

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